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# RESPONSE TO UNIAXIAL TENSION IN THE SWOLLEN STATE AND SOME NETWORK CHARACTERISTICS OF VARIOUS COMPOSITIONS OF SOLITHANE 113

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## INTRODUCTION

In a previous report on the mechanical characterization of Solithane 113 [1] the number of elastically effective network chains $\nu_e$ was calculated for various Solithane compositions on the basis of equilibrium swelling data. Mooney-Rivlin plots of uniaxial stress-strain data had only been obtained for Solithane 50/50 at the time and the more direct determination of $\nu_e$ from similar data for other compositions was not possible. In order to be able to calculate $\nu_e$ from equilibrium swelling ratios the polymer solvent interaction parameter $\mu$ was assumed to be independent of Solithane composition and the value obtained for Solithane 50/50 was used.

The results of uniaxial tension test of four different Solithane compositions swollen in Toluene are presented in this note in the form of Mooney-Rivlin plots. All compositions behave essentially neo-Hookean up to failure. The number of elastically effective network chains is calculated from this data. The interaction parameter $\mu$ could then be obtained through $\nu_e$ and equilibrium swelling data. The results show that the interaction parameter depends on the composition of Solithane 113 and cannot be considered a constant.

## EXPERIMENTAL DATA

Solithane 113 ranging in composition from 40/60 (Resin/Catalyst) to 70/30 has been tested. Toluene has been chosen as a swelling agent on the basis of previous results [1]. Figure 1 shows the volume increase $V/V_o$ in Toluene after swelling equilibrium has been reached. The higher swelling ratio reported earlier [1] for Solithane 40/60 is in error. The volume increase is seen to decrease rapidly with increasing Resin content.

The stress-strain tests were carried out with punched out dog bone shaped specimen. The device shown in Figure 2 allowed the tests to be carried out while the specimen were completely submerged in the swelling agent. The temperature was controlled within $\pm 1^{o}$ by means of copper coils through which a heated or cooled Ethyleneglycol-water mixture was pumped.

The results of these tests are shown in Figures 3 through 6 in form of Mooney-Rivlin plots. Most compositions were tested over the full range of strain rates realizable with the available cross head speeds of the Instron tester. The response is seen to be essentially neo-Hookean for all tested strain rates and compositions. The constant $C_1$ in the neo-Hookean stress-strain law

$$\sigma = 2C_1 (\lambda - \lambda^{-2}) \tag{1}$$

has been determined from this data by taking the average of $C_1$ values obtained at different strain rates. The average value for $C_1$ divided by the absolute temperature $T$ has been plotted in Figure 1 as a function of Solithane composition. The magnitude of the constant $C_1/T$ increases almost linearly with the Resin content in Solithane.

## NETWORK CHARACTERISTICS

According to the theory of rubber elasticity [2] the constant $C_1/T$ is equal to

$$C_1/T = \frac{R}{2} v_2^{\frac{1}{3}} \nu_e \tag{2}$$

where

$R$ = universal gas constant,

$v_2$ = polymer volume fraction in swollen material,

$\nu_e$ = number of elastically effective network chains per unit volume of unswollen polymer.

The stress-strain tests were all performed with the specimen being in swelling equilibrium originally. The possible volume increase due to stretching has been neglected [3]. The polymer volume fraction is thus equal to

$$v_2 = \frac{V_o}{V}$$

and the number of elastically effective network chains is readily calculated from the values of $C_1/T$. The results of this calculation are presented in Figure 7. A practically linear relationship is seen to hold between $\nu_e$ and the Resin content of Solithane.

The following relationship [4] gives the quantity $\nu_e$ in terms of the equilibrium swelling ratio

$$\nu_e = -\frac{1}{V_1} \left[ \frac{\ln(1 - v_{2e}) + v_{2e} + \mu v_{2e}^2}{g^{\frac{2}{3}} v_{2e}^{\frac{1}{3}} - \frac{2}{f} v_{2e}} \right] \tag{3}$$

where

$V_1$ = molar volume of the swelling agent,

$v_{2e} = \frac{V_o}{V}$ = polymer volume fraction at swelling equilibrium,

$g$ = volume fraction of gel rubber,

$f$ = functionality of chain junctions,

$\mu$ = polymer-solvent interaction parameter.

The volume fraction of gel rubber may be assumed to be $g = 1$ [3] and with $V_1 = 106.2 \frac{cm^3}{mole}$ for Toluene and $f = 3$ [5] the interaction parameter is readily obtained through equation (3). The interaction parameter calculated in this manner for the Solithane-Toluene system is shown in Figure 7 as a function of Solithane composition. It increases with Resin content from roughly 0.37 (40% Resin) to 0.53 (70% Resin).

The data presented in Figures 1 and 2 is also contained in Table I.

TABLE 1

| Solithane Composition (Resin/Catalyst) | $V/V_o = 1/v_{2e}$ | $C_1/T$ [psi/$^oK$] | f | g | $\nu_e x10^3$ $\left[\frac{moles}{cm^3}\right]$ | $\mu$ |
|---|---|---|---|---|---|---|
| 40/60 | 4.0 | 0.115 | 3 | ~1 | 0.304 | 0.369 |
| 50/50 | 2.7 | 0.245 | 3 | ~1 | 0.565 | 0.471 |
| 60/40 | 2.2 | 0.387 | 3 | ~1 | 0.835 | 0.51 |
| 70/30 | 2.1 | 0.485 | 3 | ~1 | 1.0 | 0.526 |

## REFERENCES


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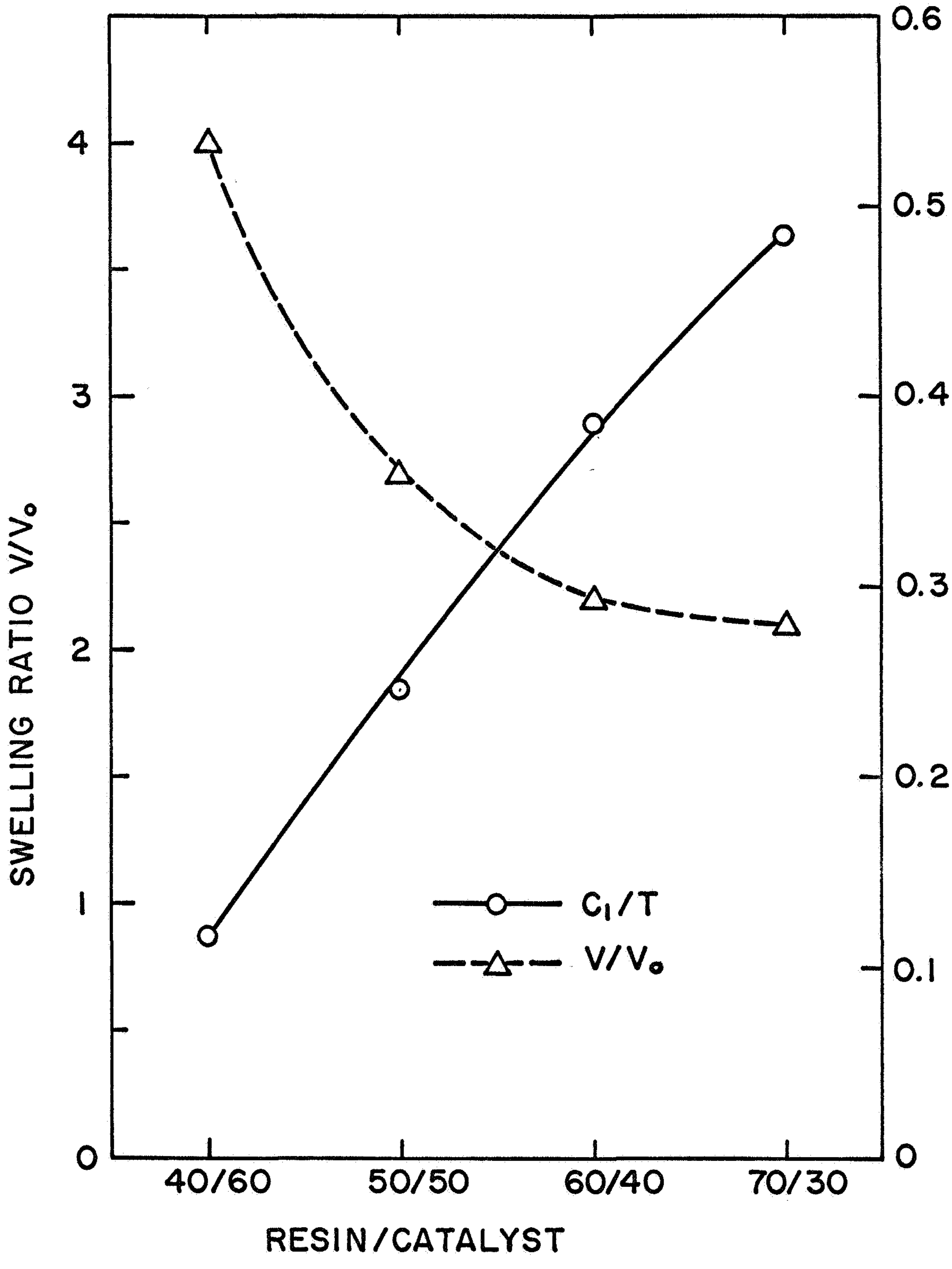


FIG. I THE SWELLING RATIO AND THE CONSTANT $C_1/T$ OF SOLITHANE 113 AS A FUNCTION OF COMPOSITION

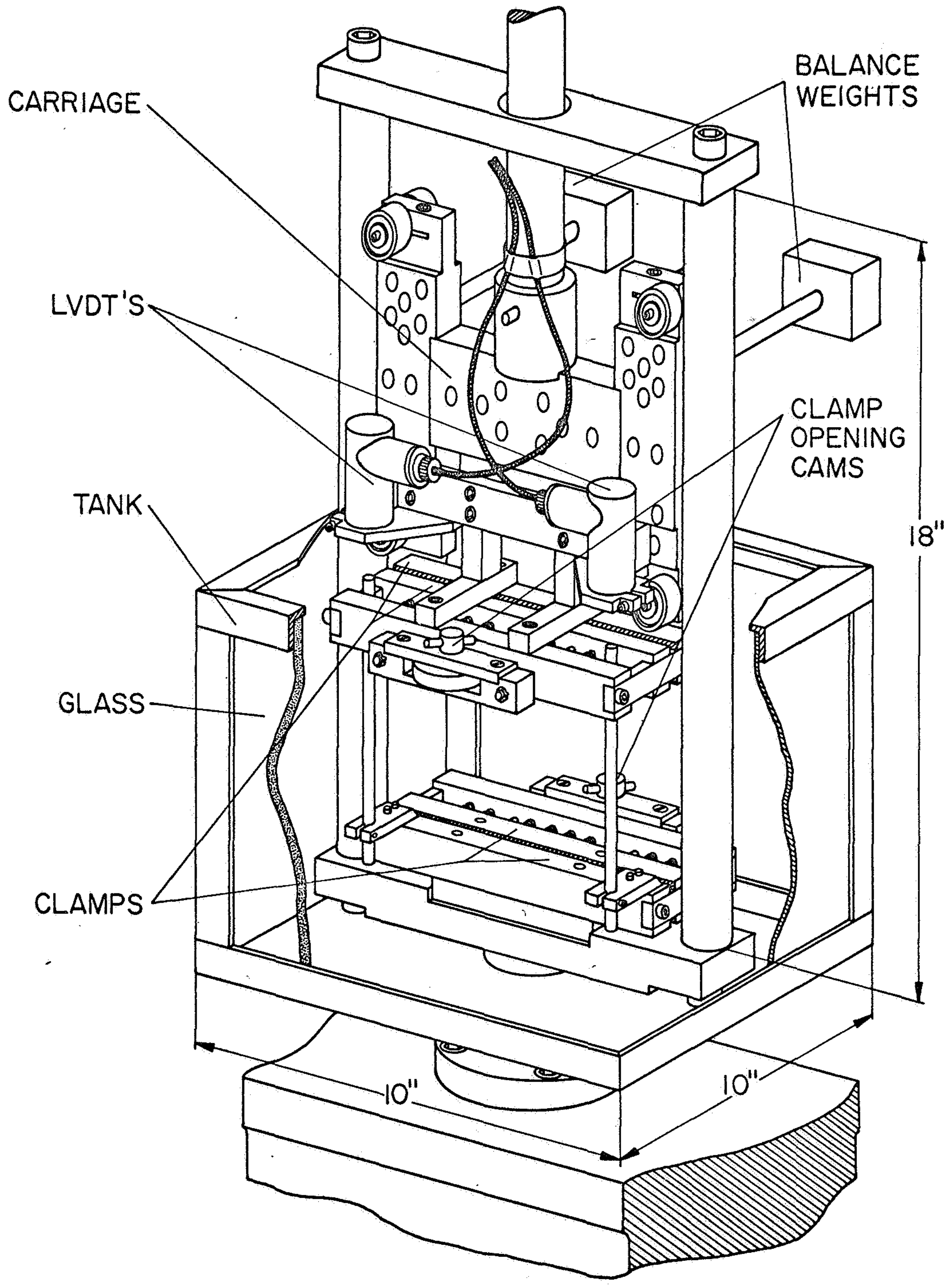


FIG. 2 DEVICE FOR THE MECHANICAL CHARACTERIZATION OF SWOLLEN SOLITHANE

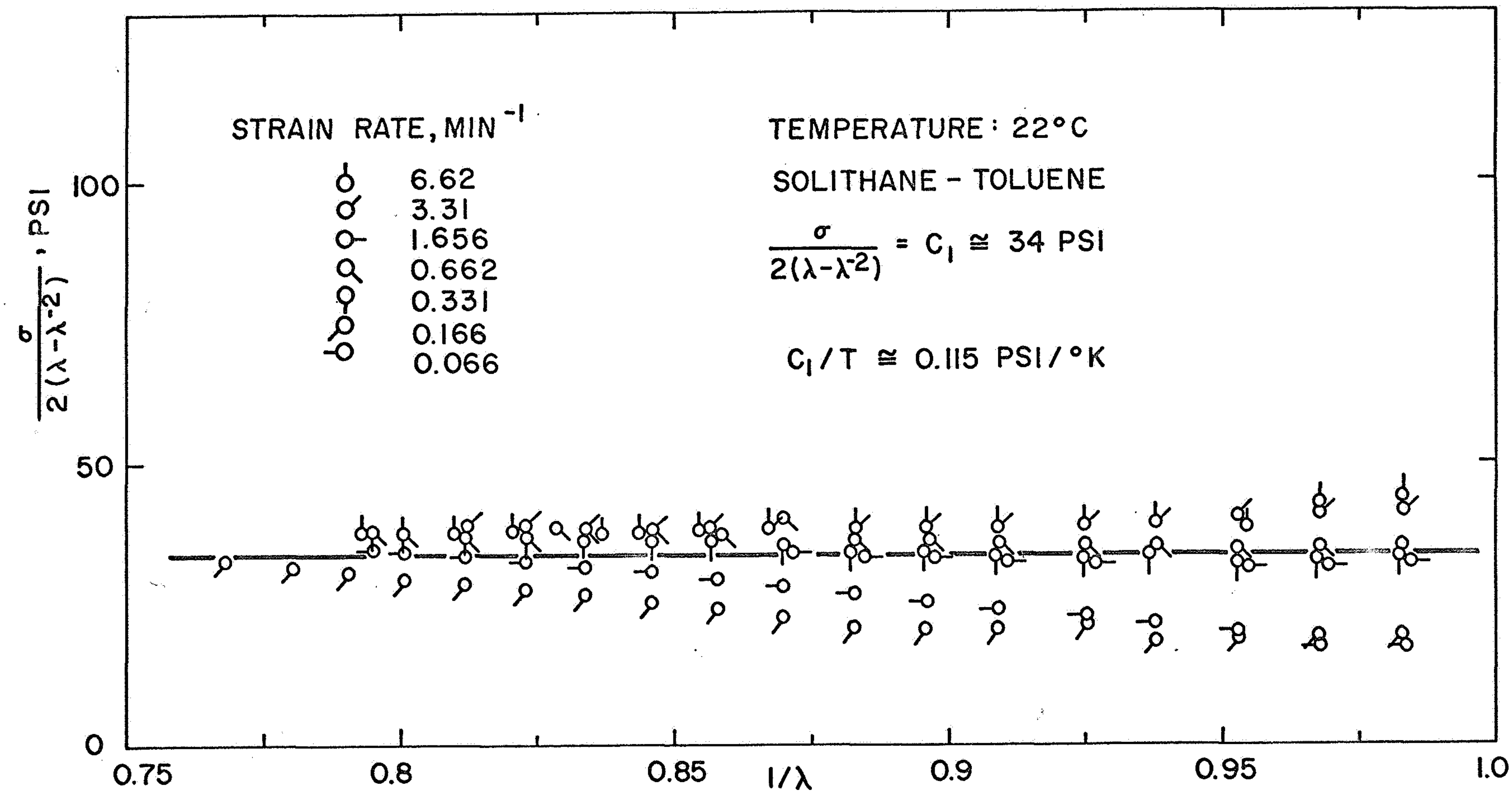


FIG. 3 MOONEY-RIVLIN PLOT FOR SWOLLEN SOLITHANE 40/60

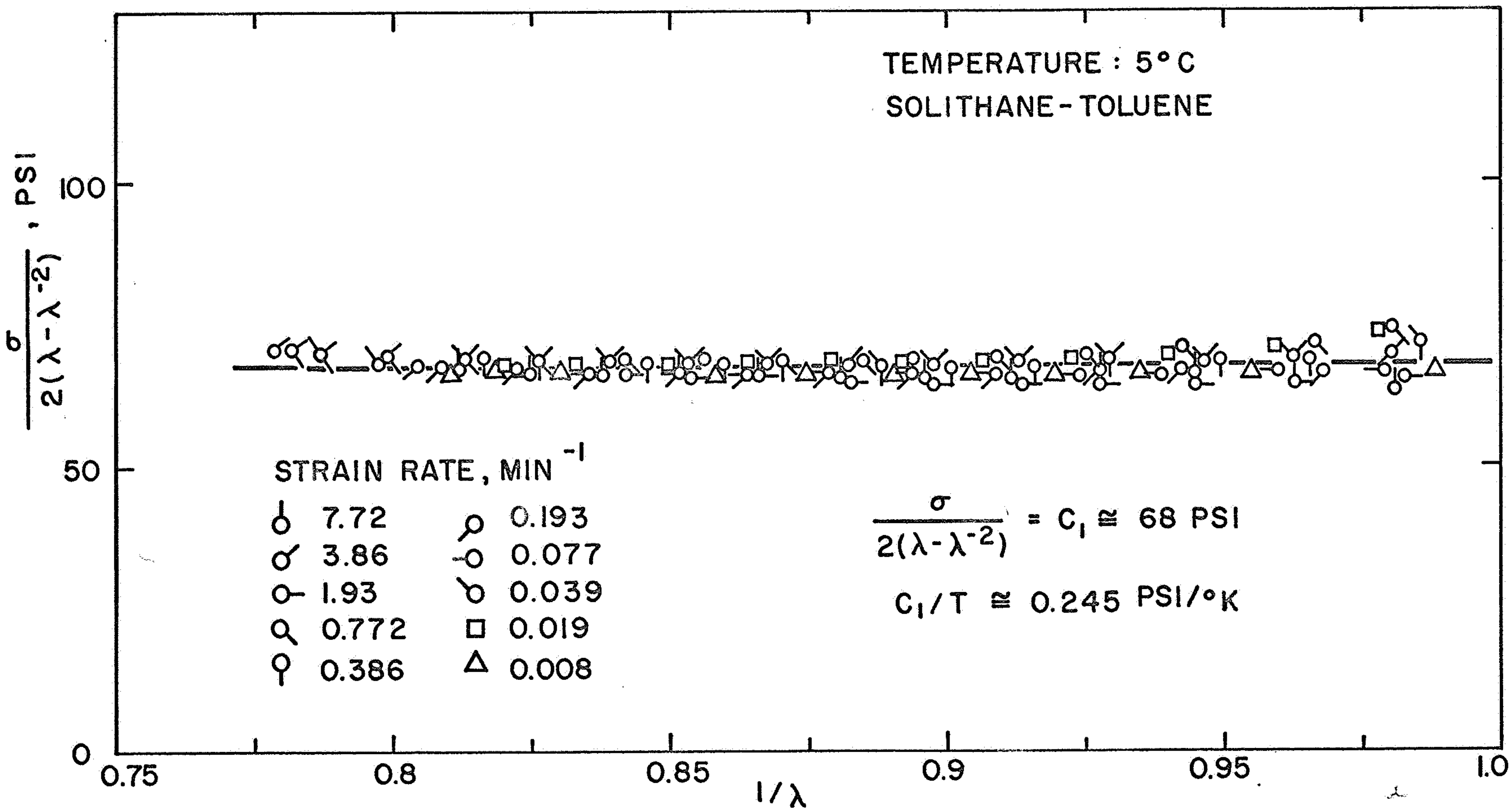


FIG. 4 MOONEY-RIVLIN PLOT FOR SWOLLEN SOLITHANE 50/50

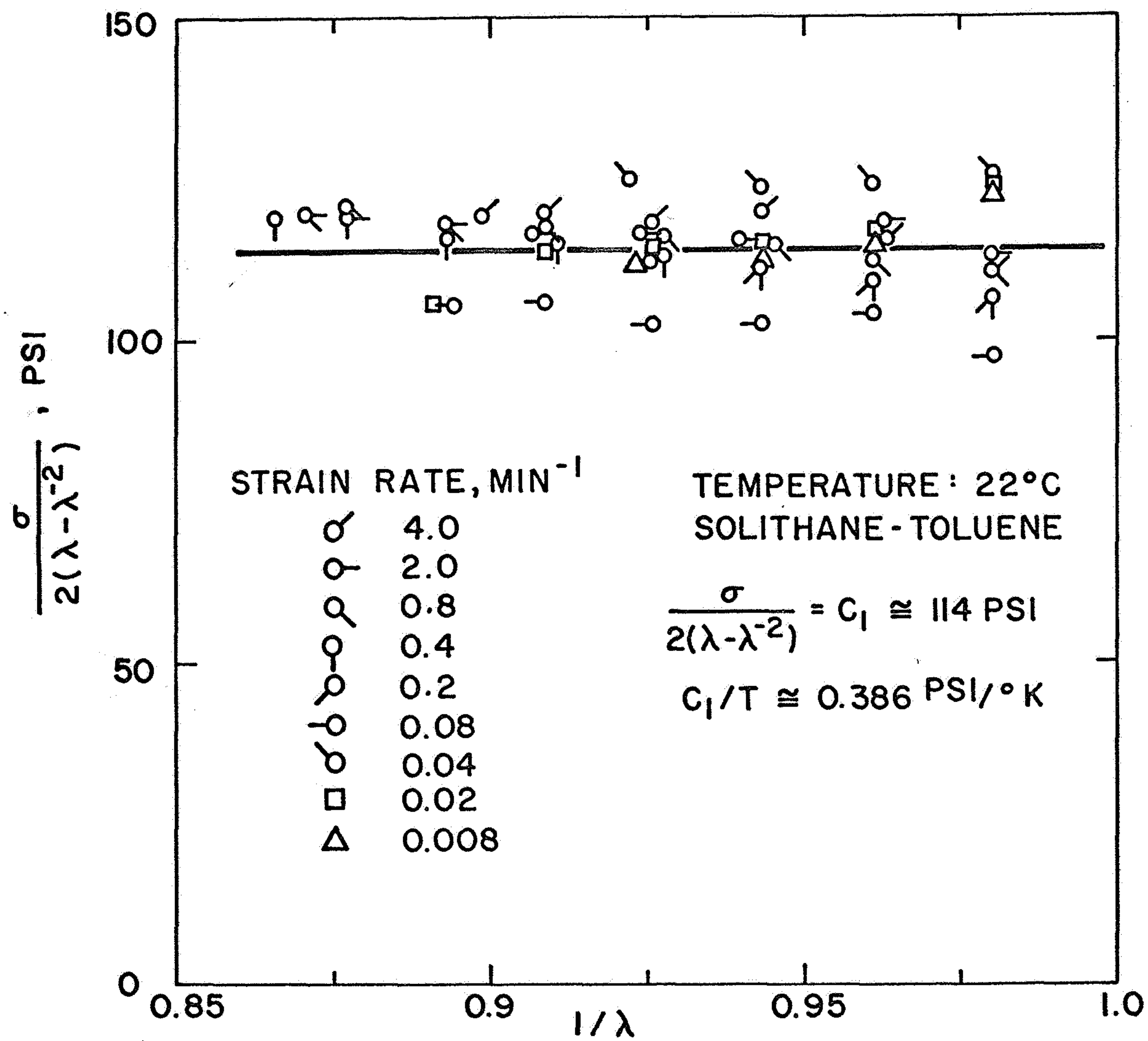


FIG.5 MOONEY-RIVLIN PLOT FOR SWOLLEN SOLITHANE 60/40

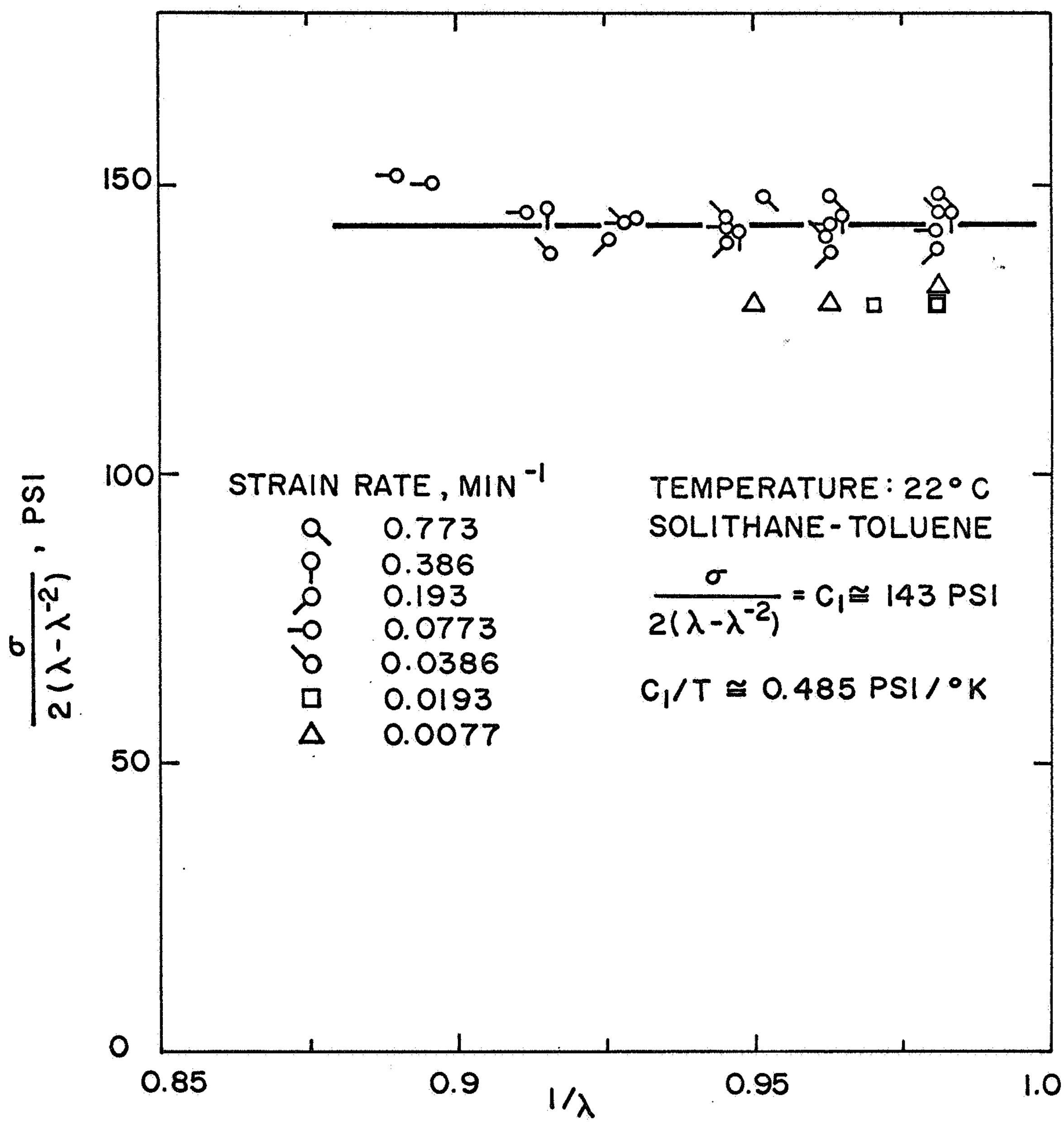


FIG. 6 MOONEY-RIVLIN PLOT FOR SWOLLEN SOLITHANE 70/30

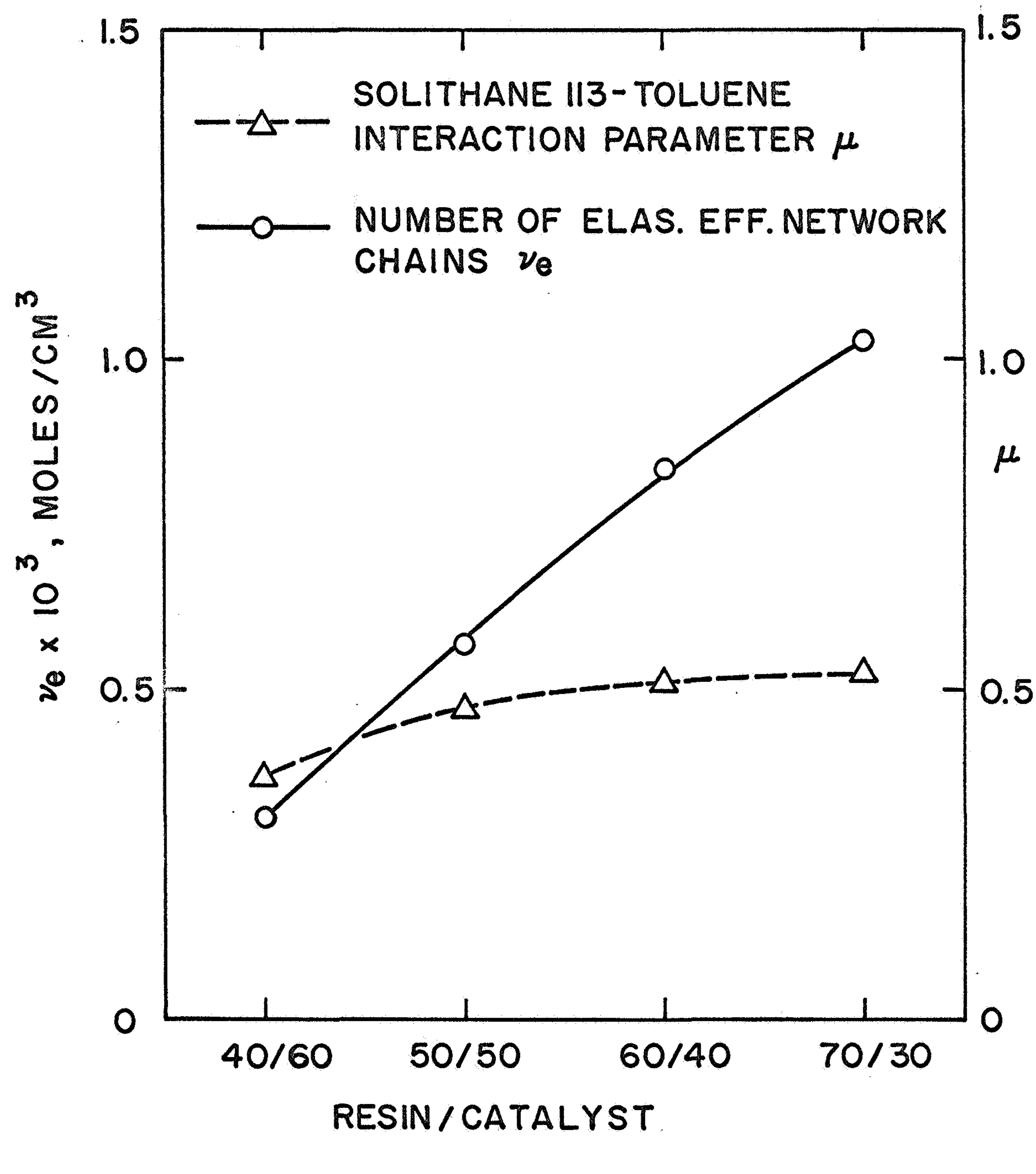


FIG. 7 NUMBER OF ELASTICALLY EFFECTIVE NETWORK CHAINS AND SOLITHANE 113-TOLUENE INTERACTION PARAMETER AS FUNCTIONS OF COMPOSITION